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# Wetland Inundation Mapping and Wetland Restoration Planning: A Case Study of Playa Wetlands, Nebraska

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# WETLAND INUNDATION MAPPING AND WETLAND RESTORATION PLANNING: A CASE STUDY OF PLAYA WETLANDS, NEBRASKA

by

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WETLAND INUNDATION MAPPING AND WETLAND RESTORATION PLANNING: A CASE STUDY OF PLAYA WETLANDS, NEBRASKA

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There has been a variety of wetland monitoring projects implemented in playa wetlands in Nebraska over the last decades. But there is still a lack of continuous wetland monitoring on long-term and large-area dimension. Because inundation condition is one of the critical parameters to describe wetland hydrologic performance, this study aims to assess the inundation alteration in playa wetlands in Nebraska and evaluate the performance of wetland conservation and restoration practices. This study uses the Landsat data to create playa wetland inundation condition maps and analyze the variation trend of inundated playa wetlands over the past 30 years. The results show that the total inundated areas from 1985 to 2015 were 220.63 $km^2$, which represents 23.61% of total area of playa wetlands. And 9,898 wetlands, representing 29.41% of total 33,659 historical wetlands, were identified as functional wetlands. The findings confirm that agricultural activities have significantly altered and degenerated the natural hydrology in playa wetlands and wetland conservation and restoration practices are crucial to protect and recover functional playa wetlands.

This study also aims to improve the effectiveness of restoration programs for the variable aspects of wetlands in playa wetlands by prioritizing the variable restoration practices. The

process includes discussing the primary threats and frequently used wetland restoration methods and identifying the principles to choose the proper restoration methods. The results identifies the most prioritized practices, including the full hydrologic restoration, partial hydrologic restoration, and vegetative restoration; and less prioritized practices, including wetland enhancement and wetland establishment. Overall, wetland restoration needs a comprehensive package of restoration methods. Any single restoration method or restoration program cannot alleviate threats that wetlands faced. The long-term restoration strategies with comprehensive methods are needed for playa wetlands.

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# CHAPTER 1 INTRODUCTION

## 1.1 Introduction to Playa Wetlands

Playa wetlands are wind-formed, ephemeral, nearly circular depressions in the Great Plains of the United States (LaGrange 2005). They play an essential role in the ecological and hydrological systems in this region (LaGrange 2005; Bartuszevige et al. 2012). Playa wetlands also play a significant role in flood mitigation, capturing sediment, capturing and filtering surface runoff, recharging the underlying aquifer, and enhancing biodiversity (LaGrange 1997; Tang et al., 2015b). In addition, Playa wetlands locate in the Central Flyway, offering critical ecological values to the migratory birds. The surrounding habitat of wetlands provide added benefit to wildlife and increase the capacity of water. Nebraska's wetlands are diverse and dynamic, including lakes, marshes, playas, fens, wet meadows, and river and stream backwaters. In this study, we only focus on playa wetlands in Nebraska because they are essential for wetland habitat, producing food, supplying water, and bird migration.

Based on the 1987 Corps of Engineers Wetlands Delineation Manual (USACE 1987), three diagnostic characteristics are used to delineate wetlands: hydrology, hydric soils, and vegetation. Thus, in order to evaluate the performance of playa wetlands, the quantitative analysis to monitor the inundation status is valuable. In this study, we use remote sensing data to identify inundation coverage areas of playa wetlands, which can be helpful for wetland managers to plan and prioritize wetland conservation programs.

In recent years, many studies have applied geospatial modeling and analysis to simulate wetland inundation dynamics. Hessa et al. (2003) used dual-season radar mosaics to produce the first high-resolution wetlands map in central Amazon basin. Gómez-Rodríguez et al. (2010) developed a linear model from Landsat data to predict water cover in Donana National Park. Muster et al. (2013) used optical and radar satellite data to identify to assess the size distribution of water bodies in three Arctic tundra wetlands. Huang et al. (2014) used statistical relationships between Landsat and LiDAR intensity data to derive subpixel inundation percentage maps in the upper Choptank River sub-watershed. Tang et al. (2014) developed a procedure with LiDAR data to delineate wetland maps and extract key parameters for playa wetlands. These studies contributed to the methodologies and technologies for wetland inundation mapping and accurate prediction; however, to improve the accuracy of wetland mapping, these models or methods focus on relatively small study areas rather than on a large scale. Because of the large scale of playa wetlands across Nebraska, a robust but effective model or index should be applied to the wetland inundation identification on state level. To date, most of conservation programs were made based on the national wetland datasets, but limited knowledge is known about the variation of the actual wetland inundation conditions in Nebraska since the national wetland datasets had been made.

**1.2 Wetland Mapping**

Accurate wetland mapping is an essential part of wetland management, which can provide geospatial information for wetland conservation programs and the judgement of effectiveness of these programs (Lang and McCarty 2009). Playa Lakes Joint Venture (PLJV) has created a region-wide database of probable playas in the Great Plains. This playas database is a compilation of multiple sources of geographic data, including National Wetlands Inventory (NWI) data, Soil Survey Geographic (SSURGO) data, National Hydrography Dataset (NHD), Landsat TM imagery, National Agricultural Imagery Program (NAIP) imagery, and some hand-delineation on aerial maps made by The Nature Conservancy. However, data source varies across the data layer because none of the data source covers the whole target area. In the case of playas in Nebraska, all were derived from the NWI data source. The establishment of the NWI during the 1970s and 1980s was aimed to develop and disseminate a comprehensive database for the Nation's wetlands (Wilen et al. 1995). However, a number of studies have reported that minimal information is available for a specific area to verify the effectiveness of the NWI maps (Stolt and Baker 1995; Kudray and Gale 2000; Rebelo et al. 2009). Although the NWI data source were not established for regulatory purpose, they have been widely used to manage wetland conservation programs on state and local level (Kudray and Gale 2000). Therefore, accurate wetland mapping is essential for wetland management. However, verification and delineation of functional wetlands has always been a challenge for wetland managers and researchers because of the continuous variation of wetland hydrology caused by social and environmental activities (Lyon and Lyon 2011). A number of studies have shown that the existing wetlands was geographically varied compared with wetlands recorded in the NWI date source (Kuzila et al. 1991; Rutchey and Vilcheck 1994; Houhoulis and Michener 2000). Kuzila et al. (1991) overlaid the 1981 NWI and the 1981 soils survey, and found that agreement between the soil survey and the NWI was 94.2% in the study portion of Nebraska's Rainwater Basin. Rutchey and Vilcheck (1994) concluded that the accuracy of the NWI data compared with SPOT satellite data was 80.9% in south Florida. Houhoulis and Michener (2000) reported that over 8% of wetlands recorded in NWI data had been converted to agricultural lands in the Ichawaynochaway Creek Basin. These studies have demonstrated that the NWI data which were primarily made in 1980s cannot perfectly fill the gap in identification and delineation between existing wetlands and historical wetlands. However, little research has been done to use remote sensing data to identify all playa wetlands in Nebraska as a supplementation or promotion of previous wetland survey.

The Rainwater Basin wetlands data were excluded from the playas database created by Playa Lakes Joint Venture (PLJV), and were obtained from the Rainwater Basin Joint Venture (RWBJV). The playa wetlands database of Rainwater Basin was a combination of the NWI data and the SSURGO data. The SSURGO data base is primarily used for farm conservation planning and watershed resource planning and management (Reybold and TeSelle 1989). Therefore, our dataset of all playa wetlands in Nebraska is a combination of PLJV wetland data and RBJV wetland data.

### 1.3 Satellite Remote Sensing in Wetland Mapping

To conserve wetland resources, manage wetland programs, and evaluate performance of existing programs, it is important to identify and monitor wetlands and their adjacent uplands. Satellite remote sensing data, especially free remote sensing data have many advantages for wetland monitor. Compared with field survey and aerial photography, remote sensing data is relatively less costly and less time-consuming, especially for the analysis of large geographic areas (Ozesmi and Bauer 2002). The digital format of remote sensing data makes it easy to integrate into the geographic information system (GIS) (Brivio et al. 2002). Satellite can regularly monitor wetland conditions, for instance, Landsat-7 sensors overpass and monitor the same area every 16 days. Moreover, based on the policy made in 2008, the United States Geological Survey (USGS) has been providing all Landsat data over the internet for free (Woodcock et al. 2008). However, satellite imagery and geospatial analysis methods also have some limitations (Gluck et al. 1996; Ozesmi and Bauer 2002; Zhu and Woodcock 2012). The overlapped spectral signatures of different wetland types make it difficult in separation (Gluck et al. 1996). Because the spatial resolution of large portion of satellite imagery are low (20-30m), it is technically difficult to identify small or long, narrow wetlands (Ozesmi and Bauer 2002). And the influence of cloud and their shadows on remote sensing data causes problems for many data analysis, including biased estimation of Normalized Difference Water Index (NDWI), misleading land cover classification, and false detection of land cover change (Zhu and Woodcock 2012). Nevertheless, satellite remote sensing has advantages in change detection studies and fuzzy classification which need repeat coverage and archival data (Singh 1989). Thus, given the advantages of satellite remote sensing, free Landsat data, including data of Landsat-5, Landsat-7, and Landsat-8, were used in this study to identify and monitor inundation condition of wetlands over the past 30 years.

### 1.4 Wetland restoration

Due to the expansion of agriculture production over the past several decades, over 85% of the historic wetlands were lost or degraded in the Rainwater Basin (Tang, et al. 2012). Although wetland restoration practices have been applied to wetlands, wetland restoration decisions are made on a project-by-project basis rather than on a holistic ecosystem perspective (White and Fennessy 2005; Voss 2007). Thus, comprehensive wetland conservation strategies are indispensable to prioritize wetland restoration programs amongst a large number of wetlands at the landscape scale.

According to Mitsch and Gosselink (1993), wetland restoration is “the rehabilitation of wetlands that may be degraded or hydrologically altered and often involves reestablishing the vegetation”. To restore wetland hydrology, hydric soils, and vegetation, a number of restoration methods have been and are used in federal and state wetland projects.

### 1.5 Research questions and objectives

This study aims to use remote sensing data and geospatial analysis method to monitor and map the wetland inundation conditions in Nebraska over the past 30 years. This study develops a new method to continue monitoring wetlands over large geographic areas and examine the actual variation of wetland inundation conditions based on remote sensing data and two original datasets. In addition, this study summarizes current wetland restoration methods and discuss the prioritization of variable restoration practices based on the study outcomes, field surveys, and some official wetland restoration guidance.

The specific research goals are as follow:

1. Create playa wetland inundation condition maps for all playa wetlands in Nebraska based on remote sensing data and two national datasets (i.e. SSURGO and NWI).

2. Use GIS geospatial analysis to monitor continuous wetland inundation conditions, and analyze the variation trend of inundated playa wetlands over the past 30 years.

3. Summarize the primary threats to playa wetlands and restoration practices in Nebraska, and prioritize wetland restoration practices.

# CHAPTER 2 METHOD

## 2.1 Study area

The major playa complexes encompasses 935 $km^2$ land across 46 counties in south Nebraska according to the PLJV wetland data and the RWBJV wetland data. This complexes include Rainwater Basin, Southwest Playas, Central Table, and the Todd Valley. The playa complexes, especially playa wetlands in Rainwater Basin, are internationally recognized for their important functions to millions of migratory water birds in each spring season (LaGrange 2005). Playa wetlands are wind-formed, ephemeral, nearly circular depressions, with a clay layer under the wetland slowing runoff water from permeating into the ground (Lane et al. 2012). Most of playa wetlands are geographically isolated, representing the lowest region in the closed watersheds (Tiner 2003). In this study, we monitor wetland inundation conditions during migratory season (i.e. March and April) within the historical playa wetland boundaries derived from the NWI data and the SSURGO data. The location of the playa wetlands is shown in figure 2.1.

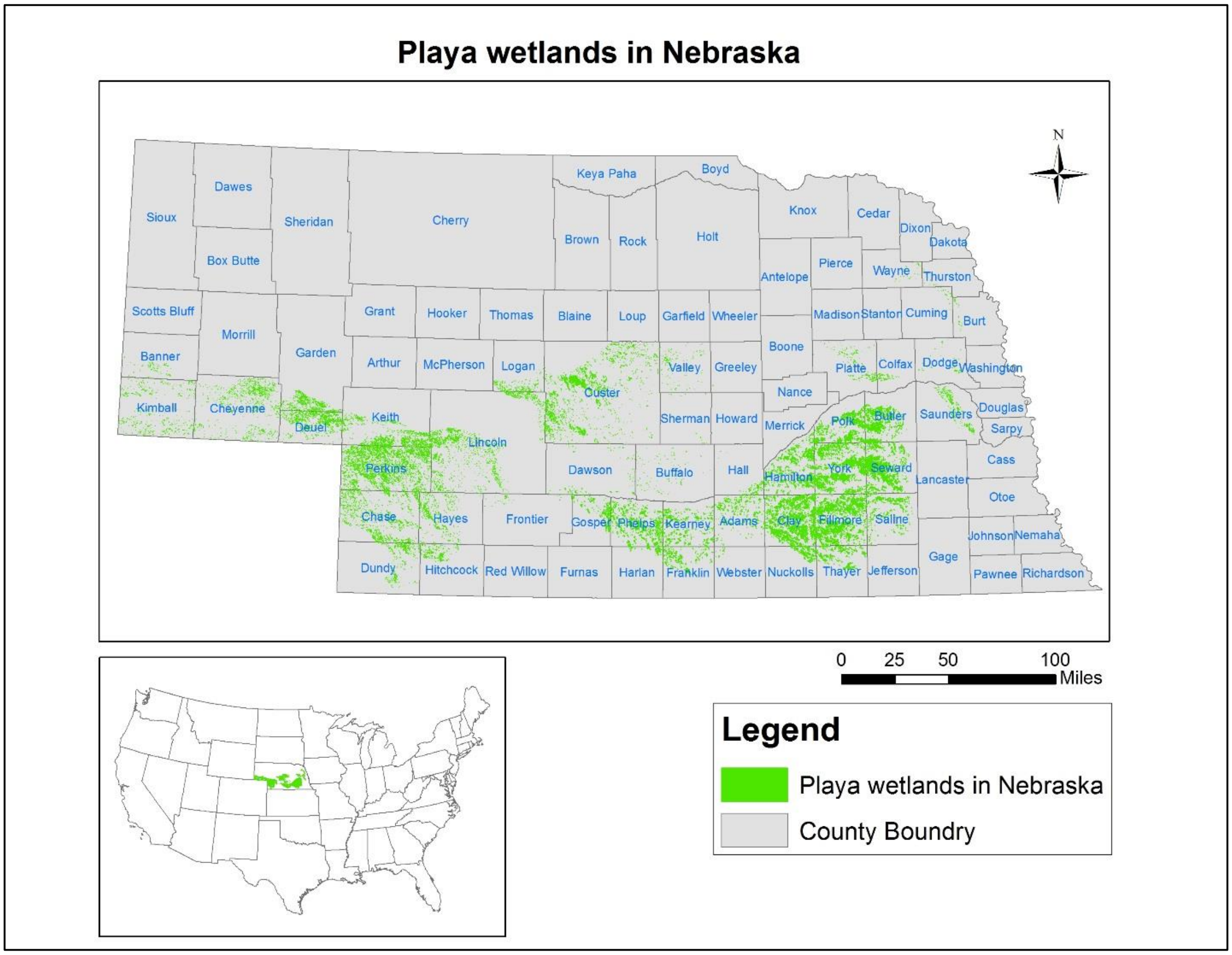


**Figure 2.1 Location of playa wetlands in Nebraska**

## 2.2 Data sources

The National Wetland Inventory (NWI) data for Nebraska is based on photointerpretation of aerial photography images collected in the 1980s. All playa wetlands in Playa Lakes region were derived from NWI coverage. Because playas were not definitely distinguished from other types of water source in the NWI, the Playa Lakes Joint Venture further developed identification methods and techniques to refine playas. Four types of land were classified as playas within wetland boundaries, including seasonally flooded land, temporarily flooded land, intermittently flooded land, and palustrine farmed land. In this study, we follow the classification of playa wetlands defined by the Playa Lakes Joint Venture.

The Rainwater Basin wetlands data were excluded from the playas database created by Playa Lakes Joint Venture (PLJV), and were obtained from the Rainwater Basin Joint Venture (RWBJV). The playa wetlands database of Rainwater Basin was a combination of the NWI data and the SSURGO data. The SSURGO data base is primarily used for farm conservation planning and watershed resource planning and management (Reybold and TeSelle 1989). For the Rainwater Basin, both the NWI data and the SSURGO data were used to conduct playa wetlands identification. The hydric soil footprint data derived from the Soil Survey Geographic (SSURGO) dataset were provided by the Natural Resources Conservation Service. Therefore, our dataset of all playa wetlands in Nebraska is a combination of PLJV wetland data and RBJV wetland data.

Landsat TM, ETM+, and OLI images were obtained from Landsat-5, Landsat-7, and Landsat-8 respectively in every March and April from 1985 to 2015 when migratory birds passing through and taking a rest in the playa wetlands in Nebraska. Table 2.1 presents general information about each Landsat satellites. All remote sensing data are from Landsat archive (http://glovis.usgs.gov). Nine scenes from different remote sensing imagery collection, which completely cover the entire playa wetland region in Nebraska, were selected to monitor wetland inundation conditions, including path/row 28-33/31 and path/row 29-31/32. The outline of Landsat imagery coverage is shown in figure 2.2.

**Table 2.1 Information of Landsat satellites**

| Satellite | Sensor | Launch date | Decommission | Resolution (m) | Repeat cycle (days) |
|---|---|---|---|---|---|
| Landsat 5 | TM | 1-Mar-84 | January, 2013 | 30 | 16 |
| Landsat 7 | ETM+ | 15-Apr-99 | Operational | 30 | 16 |
| Landsat 8 | OLI | 11-Feb-13 | Operational | 30 | 16 |

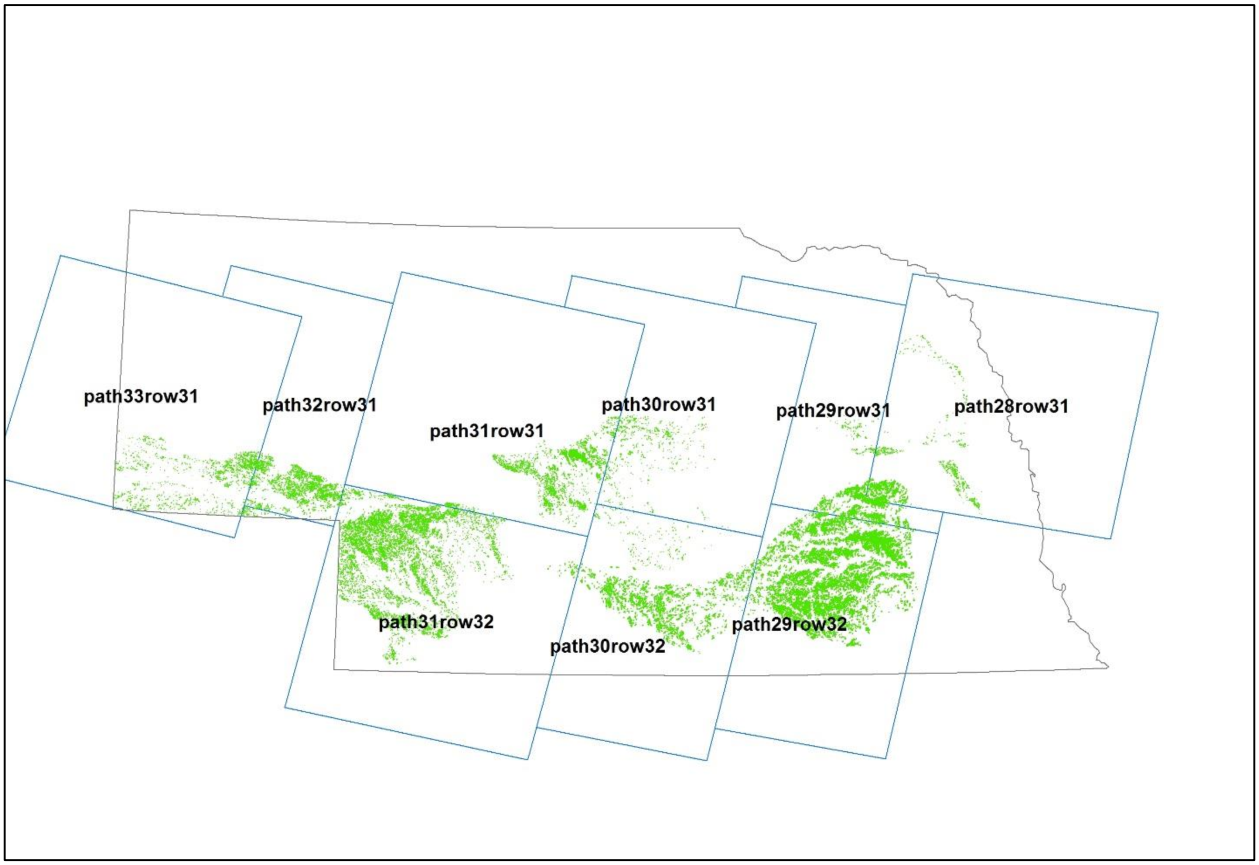


**Figure 2.2 Outline of Landsat imagery coverage on playa wetlands in Nebraska**

## 2.3 Analysis Method

This study used Google Earth Engine (Google Inc., Mountain View, CA) and ArcGIS 10.3 (ESRI Inc., Redlands, CA) to obtain and monitor dynamic playa wetlands inundation maps in every March and April over the past 30 years. The Google Earth Engine platform provides powerful functions in terabyte-scale, scientific analysis, and visualization of geospatial datasets (Gorelick 2013). This platform integrates a variety of popular datasets, including the free online collection of Landsat scenes, a large number of MODIS collections, and many vector-based datasets. All the process of data analysis will be computed by the remote server once the requirement for output is sent by users. Thus, terabyte-scale data will not be downloaded to the local computers, which largely free up space on local computers and hard disks and improve the effectiveness of geospatial analysis. In addition, through integration with other services, the Google Earth Engine is able to convert its data format to the format of Google Earth Pro, and ArcGIS. Therefore, we integrate the Google Earth Engine and the ArcGIS to analyze and monitor inundation conditions of playa wetlands in Nebraska. The primary process of geospatial analysis included five steps: (1) selecting suitable Landsat series images which are available for calculating wetland inundation conditions from USGS website; (2) calculating remote sensing raster data in Google Earth Engine; (3) converting CSV format data derived from Google Earth Engine outcomes to shapefile format in ArcGIS; (4) merging dispersive actual inundation maps calculated by Google Earth Engine based on different time period criteria; and (5) overlaying the merged actual inundation maps with the wetlands in playa wetlands dataset in ArcGIS.

This study analyzes the wetland inundation conditions during bird migration period in March and April of each year, so some criteria were set to select suitable Landsat images, including cloud coverage, snow coverage, and the date of the image. The presence of clouds, cloud shadows, and snow can significantly complicate the classification of land (Zhu & Woodcock 2012). In order to simplify the data processing, images without clouds or snow were selected as suitable images. Also, images with some clouds or snow that did not overlay wetlands were selected as suitable images based on user’s image interpretation experience. Only images taken in March or April from 1985 to 2015 were used to do image selection. Then we chose the modified normalized difference water index (MNDWI) to calculate raster data and identify inundated area. The MNDWI can efficiently suppress and even remove vegetation and soil noise, and is suitable for extracting water information (Xu 2006). The modified NDWI (MNDWI) can be expressed as follows:

$$\text{MNDWI} = (\text{Green} - \text{MIR}) / (\text{Green} + \text{MIR})$$

where MIR is a middle infrared band and Green is a green band in Landsat sensors. In Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) sensors (i.e. Landsat-5 and Landsat-7), the MIR band is band 5, and the green band is band 2. In Operational Land Imager (OLI) sensor (i.e. Landast-8), the MIR band is band 6, and the green band is band 3. We used Google Earth Engine to calculate the MNDWI for all suitable images. Only areas that are within our study area were calculated, which means only a portion of each image were calculated. Based on our previous study, ground-truth wetland data were collected to examine the accuracy of Landsat image, and a threshold value for water body was identified for extracting inundated areas from other land types (i.e. farm land and grass land). When the MNDWI value is greater than -0.12, the pixel of that value can be classified into water body. Each pixel represents a land of 30*30 $m^2$.The outcomes were saved as CSV files, and then were converted to ArcGIS shapefiles. Because many Landsat images were inevitably coved by cloud or snow, the continuity of suitable regularly images were heavily disturbed. Ideally, there are over 1,400 images in March and April for the nine scenes which cover our study area. However, only 86 images in March and 125 images in April for the past 30 years can be used to identify wetland inundation conditions. Thus, to improve the integrity of wetland inundation maps, and to effectively identify historically functional wetlands, we merged all inundated areas from different images in March and April respectively to find which areas were inundated during the past thirty years. If an area that was inundated at least once during the past 30 years, we classified the wetland which contains that inundated area as a historically functional wetland. To analyze the variation trend of functional wetlands, 30 years were divided into three 10-year periods in March and April, and the data for each 10-year period were merged into a single map. We did not conduct a finer division for 30 years, because at least a 10-year period was needed to guarantee the integrity of an inundation map that covers the whole study area.

Then the merged maps were overlaid with the playa wetland maps to examine the existence of functional wetlands and the performance of playa wetland datasets. The overall data processing is illustrated in figure 2.3.

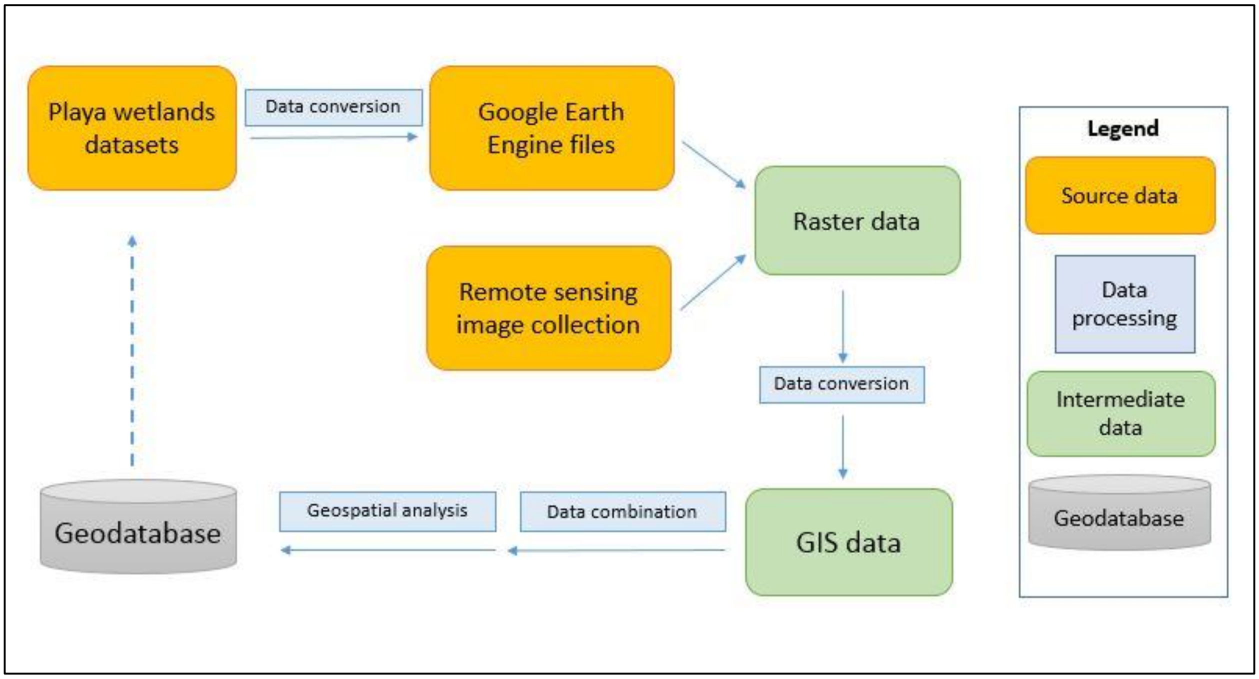


**Figure 2.3 Process of data analysis**

# CHAPTER 3 RESULTS

## 3.1 Playa wetlands inundation condition maps

The study used raster data from Landsat images to examine the extent of actual inundation areas of playa wetlands in playa wetland dataset. Google Earth Engine were used to calculate 211 images from Landsat dataset. The outcomes of raster data calculation from Google Earth Engine were digital numbers, and cannot be visualized on maps. Thus, all CSV files from Google Earth Engine were converted to shapefiles in ArcGIS to do geospatial analysis. The information of each pixel contained its unique terrestrial coordinate (i.e. longitude and latitude) on the earth, therefore, all raster pixels were positioned as points on maps in ArcGIS by coordinate orientation method. Because the resolution of all three Landsat sensors are 30 meters, each point on maps or each pixel represents a square with 900 square meters. Figure 3.1 illustrates the wetland inundation conditions for the combination of all 211 images. The blue areas on the center part of the map are wetlands that were inundated over the past 30 years. The green areas are wetlands that were never inundated based on 211 images. Two smaller pictures on the lower left corner of the map show the ponits that converted from pixels. Each point, which is the geometric center of the square, represents a quare of 900 $m^2$. Therefore, some suqares are not completely within the boundary of wetlands, especially for the wetlands that are smaller than 900 $m^2$ and some narrow and long wetlands. In this case, if the area of a wetland is smaller than the inundated area from the theoretical calculation, we counted its original area as the inundated area of that wetland.

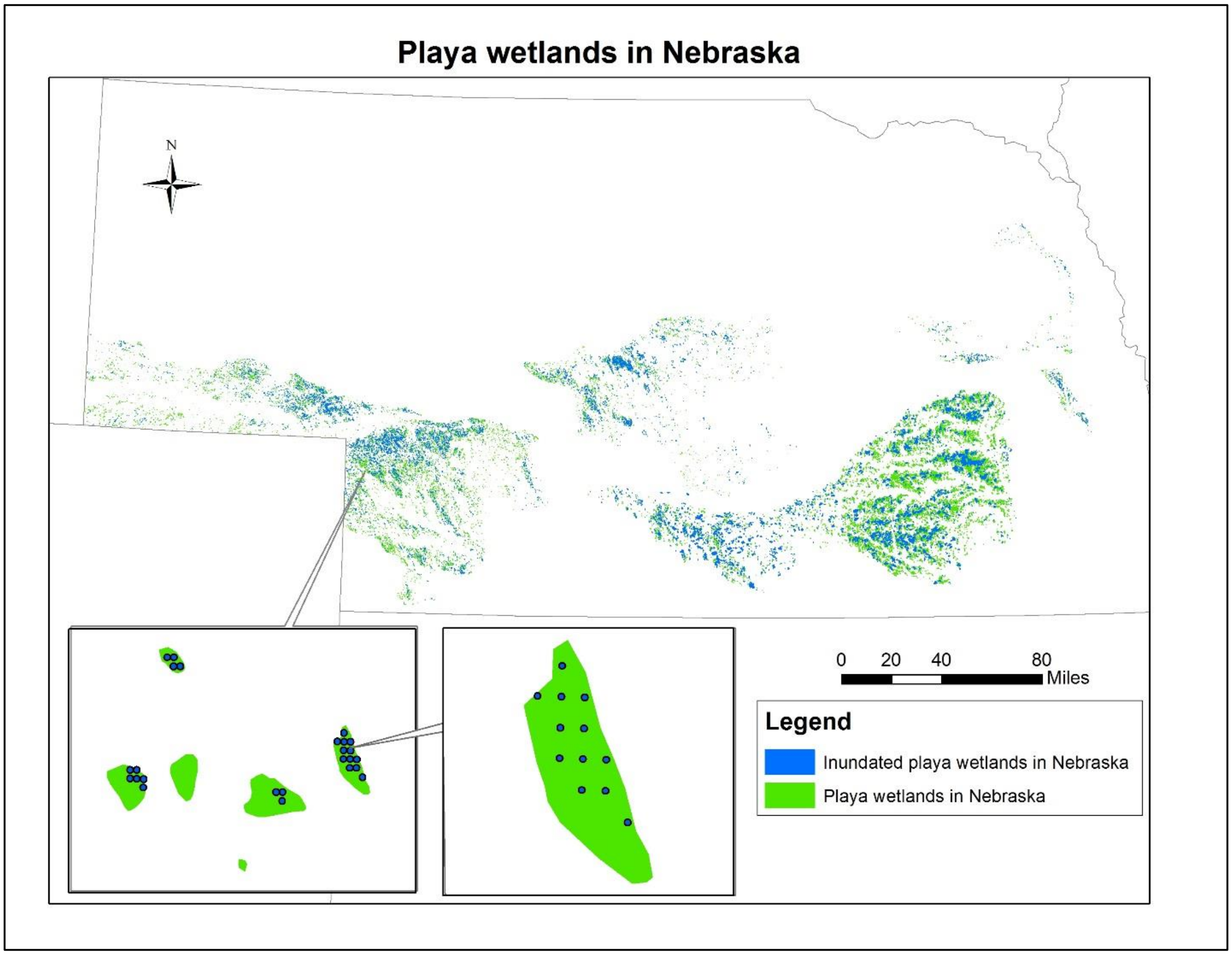


**Figure 3.1 Wetland inundation condition map**

## 3.2 Actual inundation conditions for playas in playa wetland dataset

The inundated areas and their percentages in March and April are listed in Table 3.1. The total inundated areas derived from combination of March and April data from 1985 to 2015 were 220.63 km$^2$. Compared with the total areas of playa wetlands, 23.61% of total areas were ever inundated in the past 30 years. So the acutal inundated areas were a small portion of total areas of playa wetlands. In March, 148.59 km$^2$ of footprints were inundated, representing 15.90% of total areas. And 193.24 km$^2$ of footprints that represented 20.68% of total areas were inundated in April. Based on inundated areas in March and April, it implies that 121.20 km$^2$ of areas were ever iunundated in both March and April. And 27.39 km$^2$ of inundated areas just appeared in March, while 72.04 $km^2$ of inundated areas only appeared in April for the past 30 years. Inundated wetlands in April performed better than those in March. However, the total inundated areas just partially reflected the inundation conditions of playa wetlands. Some small-sized wetlands that contained a small amount of water might be underestimated. Although they did not hold a large amount of water, they still served as fully functional wetlands and provided important habitat for migratory birds and wildlifes. Thus, another criterion, the numbers of functional mwetlands, was then used to examine the wetland inundation conditions. Wetlands where inundation fully or partially appeared within their boundaries were counted as historically functoinal wetlands. Table 3.2 shows the numbers of historically inundated wetlands. The total number of inundated wetlands in the combination of March and April data were 9898, while the total number of wetlands were 33659. Approximately thirty percent (29.41%) of total wetlands were identified as historically functional wetlands. Over senven thousand wetlands (7052 in March and 7938 in April) were identified as functional wetlands in each month period, representing 20.95% and 23.58% of total number of wetlands respectively. According to the numbers of inundated wetlands in March and April and the total number of inundated wetlands, we derived results that 5092 wetlands were functional at least once in both March and April, while 1960 wetlands in March and 2846 wetlands in April were only inundated in their respective month period. Thus, over fifty percent (51.44%) of historically inundated wetlands continually performed their function in both March and April. The results indicate that historically functional wetlands performed well in both March and April. However, these inundated areas or functional wetlands only account for a relatively small protion of total areas or numbers of wetlands in playa wetland dataset. The higher percentage of total number of functional wetlands than the percentage of total inundated areas means that more small-sized wetlands under the average area of wetlands in playa wetland dataset were functioning during the past 30 years.

**Table 3.1 Inundated areas in playa wetlands**

| | Area of inundated footprints ($km^2$) | Total area of playa wetlands | Percentage of inundated footprints in playa wetlands |
|---|---|---|---|
| **March** | 148.59 | 934.46 | 15.90% |
| **April** | 193.24 | 934.46 | 20.68% |
| **Overall** | 220.63 | 934.46 | 23.61% |

**Table 3.2 Number of inundated wetlands**

| | Number of inundated wetlands | Total wetlands | Percentage of inundated wetlands numbers |
|---|---|---|---|
| **March** | 7052 | 33659 | 20.95% |
| **April** | 7938 | 33659 | 23.58% |
| **Overall** | 9898 | 33659 | 29.41% |

## 3.3 Variation trend of inundated playa wetlands

To analyze the variation trend of inundated playa wetlands from 1985 to 2015, we devided 31 years into three time periods, including 1985-1994, 1995-2004, and 2005-2015. For each period, at least one image of each scene was selected to form a complete inundated wetland cover map for the entire playa wetland area.

Variation trend of inundated wetlands in the combination of March and April data is summarized in Table 3.3. The total number of wetlands is 33659, and the total area of playa wetlands is 934.46 km2.Among the 33659 playa wetlands, the majority were never inundated during each 10-year period. Over 6000 wetlands, accounting for 18.13% of total number of wetlands, and 179.92 $km^2$ of areas, accounting for 19.25% of total area of wetlands were inundated from 1985 to 1994. In the second 10-year period (1995-2004), 9.22% of total number of wetlands and 5.86% of total area of wetlands experienced inundated conditions. In the third 10-year period, actually 11 years from 2005 to 2015, 21.74% of total number of wetlands and 12.81 % of total area of wetlands were inundated at least once. The variation trend shows that although the number of functional wetlands reached its peak in the last 10-year period, the actual inundated areas were still in a relatively low level.

**Table 3.3 Variation trend of the combination of March and April data**

| | Numbers of inundated wetlands | Percentage of inundated wetland numbers | Area of inundated footprints ($km^2$) | Percentage of inundated footprints in playa wetlands |
|---|---|---|---|---|
| **1985-1994** | 6103 | 18.13% | 179.92 | 19.25% |
| **1995-2004** | 3104 | 9.22% | 54.75 | 5.86% |
| **2005-2015** | 7318 | 21.74% | 119.68 | 12.81% |
| **overall in March and April** | 9898 | 29.41% | 220.63 | 23.61% |
| **Playa wetlands** | 33659 | N/A | 934.46 | N/A |

Variation trend of inundated wetlands in March is summarized in Table 3.4. Only 14.08% of total number of wetlands, and 12.19% of total area of wetlands were inundated in March from 1985 to 1994. Only 5.51% of total number of wetlands, and less than five percent (4.59%) of total area of wetlands experienced inundated conditions in the second 10-year period. In the third 10-year period, 12.43% of total number of wetlands and 8.16% of total area of wetlands were inundated at least once. Both number percentage of total wetlands and percentage of inundated areas were less than 15% in each 10-year period. Among the three time periods in March, wetlands perfromed best in the first ten years from 1985 to 1994, and had the lowest perfromance from 1995 to 2004. The trend distribution patterns confirm that most of wetlands defined in playa wetland dataset were not functing in March over the past 30 years.

**Table 3.4 Variation trend of inundated wetlands in March**

| | Numbers of inundated wetlands | Percentage of inundated wetland numbers | Area of inundated footprints ($km^2$) | Percentage of inundated footprints in playa wetlands |
|---|---|---|---|---|
| **1985-1994** | 4740 | 14.08% | 113.93 | 12.19% |
| **1995-2004** | 1855 | 5.51% | 42.92 | 4.59% |
| **2005-2015** | 4183 | 12.43% | 76.24 | 8.16% |
| **Overall in March** | 7052 | 20.95% | 148.59 | 15.90% |
| **Playa wetlands** | 33659 | N/A | 934.46 | N/A |

Similar variation trend of inundated wetlands in April are listed in Table 3.5. Although there were some similarities of variation trend between March and April, the overall performance of wetlands in April was better than that in March. In the first 10-year period, 10.45% of total number of wetlands, and 15.67% of total area of wetlands were inundated in April. Approximately six percent (6.24%) of total number of wetlands and 3.92% of total area of wetlands experienced inundated conditions in the second 10-year period. The inundation conditions improved in the third period. There were  6283 wetlands and 95.47 $km^2$ of actual inundated areas with water coverage, accouting for 18.67% of total number of wetlands and 10.22% of total area of wetlands respectively. For the first 10-year period in April, it was the only period that the percentage of inundated areas was higher than the number percentage of total wetlands. Similarly, wetlands in the second period in April had lowest performance. Then the performance of wetlands turned better in the third 10-year period. However, although there were variation betwwen inundated areas in each ten-year period, the non-inundated areas were far more than the total inundated areas.

**Table 3.5 Variation trend of inundated wetlands in April**

| | Numbers of inundated wetlands | Percentage of inundated wetland numbers | Area of inundated footprints ($km^2$) | Percentage of inundated footprints in playa wetlands |
|---|---|---|---|---|
| **1985-1994** | 3516 | 10.45% | 146.44 | 15.67% |
| **1995-2004** | 2101 | 6.24% | 36.61 | 3.92% |
| **2005-2015** | 6283 | 18.67% | 95.47 | 10.22% |
| **Overall in April** | 7938 | 23.58% | 193.24 | 20.68% |
| **Playa wetlands** | 33659 | N/A | 934.46 | N/A |

## 3.4 Current threats and recommended conservation methods for wetlands

### 3.4.1 Common conservation methods for playa wetlands

Inundation is one of the component of playa wetlands, and have crucial influence on hydric soil and hydric vegetation. Wetland inundation conditions derived from wetland monitor in this study have potential guiding significance for wetland conservation plans. Thus, we sumarized current wetland restoration methods and discussed how historical inundated wetland information can be utilized for priority decisions of wetland conservations. Wetland restoration projects in playa wetlands proposed and evolved with a number of restoration methods and strategies, most of which are not periodic disturbances. Wetlands without restoration methods may negatively impact the diverse plant community and lead to monotypic stands of vegetation. Furthermore, long-term damage to wetlands may be caused by little or no restoration methods.

Table 3.6 proposed 18 restoration methods through two categories and several sub-categories, most of which are commonly used in wetland projects for hydrology restoration (NOAA, et al, 2003; Voss, 2007). Also, Table 3.7 briefly introduces the advantages and disadvantages of each method.

**Table 3.6 Categories of recommended methods**

| Categories | | Restoration Methods |
|---|---|---|
| **I. Methods to Restore Wetland Hydrology** | I-1 Wetland Fill Removal | I-1-1 Filled Wetland Construction |
| | | I-1-2 New Wetland Creation |
| | I-2 Remediation of Hydrological Modifications | I-2-1 Tile Break |
| | | I-2-2 Dam Removal |
| | | I-2-3 Ditch Plug/Fill |
| | I-3 Increase water supply to wetland | I-3-1 Pipe Installation |
| | | I-3-2 Pumping |
| | | I-3-3 Channel Excavation |
| | I-4 Water Level Control | I-4-1 Culverts with gates |
| | | I-4-2 Weirs/Check dams |
| **II. Methods to Establish a Healthy Plant Community** | II-1 Native Species Promotion | II-1-1 Wire Cage |
| | | II-1-2 Increase Nutrients |
| | II-2 Invasive Species Control | II-2-1 Herbicides |
| | | II-2-2 Mechanical Removal |
| | | II-2-3 Prescribed Fire |
| | | II-2-4 Environmental Control |
| | | II-2-5 Herbivorous Insects |
| | | II-2-6 Grazing |

**Table 3.7 Advantages & disadvantages of restoration methods**

<table>
<tr><th>Restoration methods</th><th>Brief description</th><th>Advantage</th><th>Disadvantage</th></tr>
<tr><td>I-1-1 Filled Wetland Construction</td><td>Removing the filled wetland that was filled for other land uses to restore the functions of wetland</td><td>This method is effective in restoring the functional wetlands.</td><td>This method needs a long time to work; there is a risk that leguminous species may be invasive.</td></tr>
<tr><td>I-1-2 New Wetland Creation</td><td>Creating wetland in natural upland landforms with establishment of the right soil conditions and vegetation to restore the functions of wetland</td><td>This method can effectively create a number of new wetlands.</td><td>This method requires topsoil placement to provide conditions suitable for vegetation.</td></tr>
<tr><td>I-2-1 Tile Break</td><td>Removing part of underground tile to stop field tile from draining wetlands to restore the functions of wetland</td><td>This method is easy, inexpensive, and effective in maintaining the drainage.</td><td rowspan="3">They may be expensive in construction cost and may destroy the ecological condition during construction.</td></tr>
<tr><td>I-2-2 Dam Removal</td><td>Removing dams or other kinds of water control construction, which are deterrents to water supply to wetland, to restore the loss of wetland hydrologic characteristics</td><td>It can effectively maintain the drainage and increase water supply to wetland.</td></tr>
<tr><td>I-2-3 Ditch Plug/Fill</td><td>Establishing the controlling elevation along the ditch to eliminate the impacts of excavated ditches</td><td>This method is easy, inexpensive, and effective in reducing the impacts of ditches.</td></tr>
<tr><td>I-3-1 Pipe Installation</td><td>Installing either underground or above-ground pipes to supply water from adjacent areas to wetland</td><td>It can effectively increase the water supply to wetland site and.</td><td>This method may be expensive and destroy the wetland ecology during construction.</td></tr>
<tr><td>I-3-2 Pumping</td><td>Use mechanical equipment to pump additional water from</td><td>This can efficiently increase the water supply to the wetland</td><td>This method just can be used in a specifically short</td></tr>
</table>

| | | | |
|---|---|---|---|
| | other sites to wetland to reduce the impact of drought | site and supplement the wetland hydrology and the habitats of migratory birds. | time annually; and it may destroy the ecological balance. |
| **I-3-3 Channel Excavation** | Digging open channels to conduct water flow from adjacent upland to wetland to increase water supply | This method can effectively increase water supply to wetland. | The construction cost heavily relies on the length of channels and the surrounding topography situations. |
| **I-4-1 Culverts with gates** | Using Culverts can connect the drainage of adjacent wetlands or control the water level with gates | This method can effectively control water levels in wetland to adopt the habitat of migratory birds. | This method may be expensive in construction and maintains; the culvers under roads may need the permit of transportation agencies. |
| **I-4-2 Weirs/Check dams** | Using these water control structures to control the water supply to wetland if the water supply is often over capacity of wetland | This method can effectively control water supply to wetland to adopt the habitat of migratory birds. | The change of drainage may have potential impacts of ecology in wetland; the cost of construction and maintains may be expensive. |
| **II-1-1 Wire Cage** | Putting wire cages around planted seeds, roots, and shoots to protect new plants of native species from herbivores | This method can efficiently protect the new plants of native species with low cost. | The corrosion of mental may pollute the wetland environment. |
| **II-1-2 Increase Nutrients** | Using native leguminous species to boost nutrients (nitrogen) in wetland soil to support growth of plant species | This method can increase the nutrients in soils ecologically, which is better than the chemical methods. | This method needs a long time to work; there is a risk that leguminous species may be invasive. |
| **II-2-1 Herbicides** | Controlling the spread of common reed and other invasive species with chemical agents | This can control the invasive species effectively, such as glyphosate and imazapyr. | Some kind of chemical agents may be harmful to public health; and it cannot eliminate the species entirely. |

| | | | |
|---|---|---|---|
| **II-2-2 Mechanical Removal** | Cutting, plowing, or grading of the impacted wetlands to control the invasive species | This is one of the most effective ways to control the spread of purple loosestrife or common reed; and it can work effectively with the herbicide treatment. | The mechanical equipment requires a substantial investment of labor to control and maintain. |
| **II-2-3 Prescribed Fire** | Removing excess biomass after he herbicides, killing any living rhizomes, and promoting native plant growth | This is inexpensive and ecologically sound to control Phragmites, especially in large dense Phragmites stands. | Without first use of herbicides, this cannot work effectively and may encourage rhizome growth. |
| **II-2-4 Environmental Control** | Decreasing the vitality of invasive species by changing the surrounding environment such as pH, and soil condition | This can effectively control the spread of loosestrife. | Without combination with other techniques, this cannot be successful in controlling Phragmites. |
| **II-2-5 Herbivorous Insects** | Importing some herbivorous insects which feed on the invasive species to reduce the spread of invasive species | This is one of the most efficient, sustainable, and inexpensive strategies to control the spread of invasive species. | This method cannot work in a short term; and the new species of insects may result in other ecological issues. |
| **II-2-6 Grazing** | Grazing can severely injure the invasive species. Specifically, The cow's hooves can destroy the root systems of invasive species as the cows move through the grazing wetlands. | This method can partially limit the spread of invasive species and promote the water supplement for wetland. | This method is not so effectively control the spread of invasive species. |

### 3.4.2 Current threats of wetlands and recommended methods

The study summarizes the primary threats and recommended restoration practices for the wetlands. The strategies follows the Rainwater Basin Joint Venture Implementation Plan (RWBJV, 2013), including wetland conservation to increase wetland acres, wetland restoration to improve hydrologic function (i.e. the number of acres that pond water) and habitat conditions. There are nine primary threats: functional conversions, topographical alterations, sediment/siltation, invasive species, woody invasion, overgrazing, fragmentation, repetitive management, and extended vacancy. These threats could significantly affect the wetland and habitat conditions, and modify natural hydrology of playa wetlands. Restoration methods listed above are applied to recommended methods. Table 3.8 lists these major threats and provides brief descriptions and possible solutions.

**Table 3.8 Threats for Wetlands**

| Threat Types | Brief Description | Recommended methods |
|---|---|---|
| Functional Conversion | Seasonal wetlands may be easily converted to agricultural cropland, building site, roads, feedlots, and other uses. | I-1-1 Filled Wetland Construction;<br>I-2-1 Tile Break;<br>I-2-2 Dam Removal;<br>I-2-3 Ditch Plug/ Fill;<br>I-3-1 Pipe Installation;<br>I-3-2 Pumping; |
| Topographically alteration in the Watershed | Alterations can damage the natural hydrology of watershed area, including concentration pits, terraces, diversions, stream channelization, ditches, and others. | I-1-2 New Wetland Creation;<br>I-2-2 Dam Removal;<br>I-2-3 Ditch Plug/Fill;<br>I-3-3 Channel Excavation;<br>I-4-1 Culverts with gates;<br>I-4-2 Weir/Check Dams |
| Sediment / Siltation | Culturally-accelerated sedimentation alters the natural depths and hydro-periods of wetlands and invites invasive plant species. | I-1-1 Filled Wetland Construction;<br>I-4-1 Culverts with Gates; |
| Invasive species | The invasive species can form dense monotypic stands that reduce habitat diversity, including reed canary grass, hybrid cattail, common reed, river bulrush, purple loosestrife, salt cedar, and others | II-2-1 Herbicides;<br>II-2-2 Mechanical Removal;<br>II-2-3 Prescribed Fire;<br>II-2-4 Environmental Control;<br>II-2-5 Herbivorous Insects;<br>II-2-6 Intense Grazing |
| Woody invasion | Trees in wetlands provide habitat and perch sites for predators. The tree removal methods for wetland restoration are often expensive. | II-2-2 Mechanical Removal;<br>II-2-3 Prescribed Fire;<br>II-2-4 Environmental Control; |

| | | |
|---|---|---|
| Overgrazing | Continued heavy grazing can shift the plant community by killing plants and reducing the number of young replacement plants, and lead to loss of native plant diversity, invasion by non-native species, and uniform vegetative structure. | II-2-1 Herbicides; II-2-2 Mechanical Removal; II-2-3 Prescribed Fire; II-2-4 Environmental Control; II-2-5 Herbivorous Insects |
| Fragmentation | Fragmentation leads to increased and more rapid invasion by non-native and aggressive species, loss of genetic diversity, degradation of wildlife habitat, and others. | I-1-1 Filled Wetland Construction; I-1-2 New Wetland Creation; I-2-2 Dam Removal; I-2-3 ditch Plug/Fill; |
| Repetitive management | Conducting the same management can lead to a reduction of plant diversity and invasion of non-natives. | Using a variety of techniques and applying them at different times of the year |
| Extended vacancy | Long-term rest leads to loss of native plant diversity along with increased abundance and invasion by non-native and aggressive wetland plant species. | Using a variety of techniques and applying them at different times of the year to reduce the long-term rest |

### 3.4.3 Priority of wetland practices

Based on the Wetland Priority Practices (LaGrange, 2010) from the Nebraska Game and Parks Commission's manual, the restoration activities are categorized into four level of priorities. In Priority 1, wetland restoration can be divided into three parts: fully hydrologic restoration, partial hydrologic restoration, and vegetative restoration. Fully hydrologic restoration means re-establishment. On these areas, wetlands have been fully drained but historically were wetlands and need to be recovered. Partial hydrologic restoration is similar to fully hydrologic restoration, of which the difference is that wetlands on these areas have just been partially drained. Vegetative restoration, aims to restore natural plant communities on areas where vegetation types have been mainly altered. Priority 2, wetland vegetation management and maintenance, intends to improve or maintain current desirable vegetation. Priority 3, wetland enhancement, is to alter some physical characteristics of existing wetlands. Some specific benefits will be achieved by altering the natural ecological and hydrologic functions, for example, a seasonal wetland turning into a semi-permanent wetland. In priority 4, wetland establishment means establishing a wetland that did not previously exist.

Based on the strategies in each category, related restoration methods are different. Following the intention of each category, 18 recommended restoration methods listed in 3.4.1 section were classified into 6 categories (Table 3.9). Some of methods were classified twice or more into different categories because these methods fits in various intentions.

**Table 3.9 Related methods of Wetland Priority Practices**

| Category | Related Methods |
|---|---|
| P1-a Fully Hydrologic Restoration | I-1-1 Filled Wetland Construction;<br>I-2-1 Tile Break;<br>I-2-2 Dam Removal;<br>I-2-3 Ditch Plug/Fill;<br>I-3-1 Pipe Installation;<br>I-3-2 Pumping;<br>I-3-3 Channel Excavation;<br>I-4-1 Culverts with gates;<br>I-4-2 Weirs/Check dams; |
| P1-b Partial Hydrologic Restoration | I-1-1 Filled Wetland Construction;<br>I-2-1 Tile Break;<br>I-2-2 Dam Removal;<br>I-2-3 Ditch Plug/Fill;<br>I-3-1 Pipe Installation;<br>I-3-2 Pumping;<br>I-3-3 Channel Excavation;<br>I-4-1 Culverts with gates;<br>I-4-2 Weirs/Check dams; |
| P1-c Vegetative Restoration | II-1-2 Increase Nutrients;<br>II-2-1 Herbicides;<br>II-2-2 Mechanical Removal;<br>II-2-3 Prescribed Fire;<br>II-2-4 Environmental Control;<br>II-2-5 Herbivorous Insects;<br>II-2-6 Grazing; |

| | |
|---|---|
| P2 Wetland Vegetation management and maintenance | I-1-1 Filled Wetland Construction;<br>II-1-2 Increase Nutrients;<br>II-1-2 Increase Nutrients; |
| P3 Wetland Enhancement (Alteration) | I-1-1 Filled Wetland Construction;<br>I-3-1 Pipe Installation;<br>I-3-3 Channel Excavation;<br>I-4-1 Culverts with gates;<br>I-4-2 Weirs/Check dams; |
| P4 Wetland Establishment (Creation) | I-1-2 New Wetland Creation |

Table 3.9 summarized the related methods for each category, providing optional methods for different level of practices. Oftentimes, comprehensive plan is needed for wetland conservation and restoration. In order to restore or build a fully functional playa ecosystem, restoration methods will need to be implemented in conjunction with each other (LaGrange and Stutheit 2011). Thus, in each category of Wetland Priority Practices, several methods would be applied to restoration as a whole, depending upon the condition of each specific wetland.

# CHAPTER 4 DISCUSSION

## 4.1 Application of Google Earth Engine and Landsat imagery

This study used a cutting-edge platform, Google Earth Engine, to calculate remote sensing data and monitor wetland inundation conditions. The application of Google Earth Engine in this study further explored methods and techniques for wetland monitor over large geographic areas. Many previous studies have developed methodologies for wetland mapping (e.g., Kuzila et al. 1991; Hessa et al. 2003; Gómez-Rodríguez et al. 2010; Muster et al. 2013; Huang et al. 2014). However, most of these focused on accuracy analysis, which have deficiencies in monitoring long-range, long-time, and large-scale environment. To date, there are more than 1400 Landsat images for nine scenes that cover the playa wetlands in Nebraska in spring over the past 30 years. The size of each image is over one gigabyte, and the total size of all images is over one terabyte. Therefore, a hard drive with the capacity of one terabyte is still not enough for storing 1400 Landsat images. Although only 211 images used in this study, of which the total size is approximately 300 gigabyte, can be stored in either local computers or hard disks, the continuous and fast-growing wetland monitoring data would still be a challenge for individual researchers to hold and process. Google Earth Engine allows users to calculate remote sensing data online through remote servers, and returns outcomes as small-sized data format files. Thus, once the requirement for computing remote sensing data was sent to this platform by users, the gigabyte-scale target images will be calculated online without having to be downloaded to local computers. In this study, the size of calculated outcomes from Google Earth Engine is approximately 7 gigabyte. Compared with the size of 211 Landsat images, Google Earth Engine largely frees up space on local computers and hard disks, and improves the effectiveness of geospatial analysis.

The application of Landsat images enormously reduce the cost of the research. Because of a policy change, all Landsat data became freely available in 2008 (Woodcock et al. 2008). The continuity of free Landsat images make long-term and large-area investigations become possible, especially for understanding the dynamic of ecology and land cover changes (Kennedy et al. 2009). However, the limitations and advantages of Landsat data should be noticed. Based on the resolution of Landsat sensors, Landsat data cannot provide detailed information which can be provided by Lidar data, aerial photos or field surveys, however, it is appropriate for continued monitoring of wetlands over large geographic areas (Ozesmi and Bauer 2002). It is also a promising technique for wetland change detection, because it can identify continuous land type changes and areas where more accurate information must be gathered from higher resolution sensors. But one factor significantly affect the continuity of useable Landsat images. Zhang et al. (2004) reported that approximately 66% of surface of the earth is annually covered by cloud. Thus, many of Landsat images are inevitably influenced by cloud. In this study, influenced by cloud cover and location of wetlands, only approximately 15% of available images can be used. Even so, for state or local wetland managers and planners, some more accurate data (e.g. Lidar data and aerial photos) may not always be the best choice for wetland monitor, because many of these types of data are tremendously costly and cannot provide multi-temporal images. To date, because of the limited resources and funding, Lidar data and aerial photos do not cover the whole state of Nebraska. Thus, continuous free Landsat images were chose in this study to monitor wetland inundation conditions.

**4.2 Playa wetlands inundation condition mapping**

The ideal case of this study is to monitor annually spring wetland inundation conditions over the past 30 years. However, a large portion of Landsat images were affected by cloud. Some images were also covered by snow. Thus, among the 1400 images, 211 images of nine scenes are useable for playa wetlands monitor. The distribution of usable images are listed in Table 4.1. The distribution of usable images indicates that neither total number of images for each scene nor images of each scene in each month period (i.e. March and April) are sufficient to monitor wetland changes from year to year. In March, the most productive scene is Path 31/ Row 32, of which 13 images are useable, while only 4 useable images are useable in Path 33/ Row 31 for the past 30 years. In April, the easternmost scene of Path 28/ Row 31 is the most productive scene, of which 21 images are useable. Both Path 32/ Row 31and Path 33/ Row31, which cover the westernmost playa wetlands in Nebraska, only have 9 images respectively. Even for the combination of all images from March and April, there are no scene that the number of its images is greater than the number of years monitored in this study. It indicates that there is a technical gap between theoretical wetland monitor and practical wetland monitor.

**Table 4.1 Distribution of useable images in each scene**

| | **P28 R31** | **P29 R31** | **P29 R32** | **P30 R31** | **P30 R32** | **P31 R31** | **P31 R32** | **P32 R31** | **P33 R31** | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|
| **March** | 8 | 12 | 12 | 10 | 9 | 8 | 13 | 10 | 4 | 86 |
| **April** | 21 | 12 | 12 | 16 | 12 | 16 | 18 | 9 | 9 | 125 |
| **Overall** | 29 | 24 | 24 | 26 | 21 | 24 | 31 | 19 | 13 | 211 |

Given the situation we encountered, the annually wetland change detection would be impossible to achieve. Then two methods were set to assist us in monitoring and analyzing wetland inundation conditions and their variation trends. Firstly, an outline of inundated areas for all playa wetlands, including all of inundated areas identified in 211 images, were combined into a single map. The inundated areas in this map represent historically inundated areas where inundation appeared at least once during the past 30 years. The original inundation information are represented by points derived from raster data. There are 262,803 points, representing 236.

53 $km^2$ of areas were inundated. However, although each point represents the central point of a square of $900m^2$ and all points locate in the playa wetlands, some of the squares are not completely within wetland boundaries. The variation of inundated wetland may be caused by many reasons, including hydrology variation, land use change, and agricultural activities. This study aims to examine the performance of previous wetland datasets. Thus, we modified the inundated areas based on existing playa wetland boundaries. If the theoretical calculated value of inundated area is larger than the area of its wetland, the area of that wetland will be counted as actual inundated area. The modified result shows that totally 220.63 $km^2$ of areas were identified as inundated areas in playa wetlands. Approximately a 7% (15.9 $km^2$) of areas indicate the difference between all inundated areas in and around the playa wetland and inundated areas only in playa wetlands. The percentage of inundated area of in playa wetlands is 23.61%, which indicates that just a small portion of wetlands were inundated at least once during past 30 years. This result is consistent with a previous study (Tang et al. 2015a) which examined inundation conditions in Rainwater Basin. In their study, 13.3 % of areas in SSURGO dataset and 30.7 % of areas in the NWI dataset defined as wetlands were inundated over an eight-year period. Although inundation condition is just one of three diagnostic characteristics that used to delineate wetlands, including vegetation, hydric soils, and inundation by water, the lack of inundated land in wetlands is still an important signal for wetlands in low functional level or is an indication of insufficient wetland monitor (Tang et al. 2015a). So this study contribute to the wetland monitor for playa wetlands in Nebraska, especially wetlands in west Nebraska where few efforts have been made to detect and monitor changes.

Because the resolution of Landsat imagery is 900 $m^2$, the effectiveness of wetland detection for small wetlands which are less than 900 $m^2$ should be further discussed. Wetlands that less than 900 $m^2$ is definitely smaller than the area of one pixel in Landsat image, so the area of each wetland was counted as its inundated area if the wetland was inundated. Based on this count method, the smallest footprint that has been identified from Landsat images is 220 $m^2$. The number of inundated footprints that have been detected is 247, while the total number of footprints that less than 900 $m^2$ is 4490. The number percentage of inundated footprints among wetlands that less than 900 $m^2$ is 5.5%. In addition, the total number of inundated footprints is 9898, while the total number of footprints is 33659. The number percentage of inundated footprints among all wetlands is 29.4%. Thus, less footprints that less than 900 $m^2$ have been identified as inundated wetlands. From this point of view, we probably underestimated inundated footprints that less than 900 $m^2$ because of the limitation of Landsat imagery. However, how these small inundated wetlands contribute to the predominating inundation areas is also need to be discussed. The total area of inundated footprints that less than 900 $m^2$ is 0.17 $km^2$, while the total area of inundated footprints is 519 $km^2$. The percentage of inundated footprints that less than 900 $m^2$ among all inundated footprints is 0.03%. Furthermore, the total area of footprints that less than 900 $m^2$ is 2.78 $km^2$, and the total area of footprints is 934 $km^2$. The percentage of footprints that less than 900 $m^2$ among all footprints is 0.3%. Thus, although small size playa wetlands are ecologically important, they do not contribute to the predominating inundation areas.

**4.3 Variation trend of inundated playa wetlands**

The second method for monitoring and detecting variation trend of wetlands is dividing 30 years into three 10-year periods. To analyze variation trend, a continuous temporal change should be monitored, especially changes from year to year. However, cloud cover and snow are obvious constraint for optical remote sensing data collection, which had been reported by a number of studies (Kontoes and Stakenborg 1990; Irish 2000; Sano et al. 2007; Zhu and Woodcock 2012). As listed in Table 4.2 and Table 4.3, there are five 10-year periods in both March and April on which some of scenes only have one useable image because of cloud cover and snow. Thus, in this study, no finer division of time period can reflect the integrity of inundation conditions for whole playa wetlands, and 10-year periods were used. One difference among 10-year periods is that from 2005-2015 in both March and April the numbers of useable images are significantly increased as almost twice as those in the first and second 10-year periods, which is due to the launch of Landsat-7 in 1999 and the launch of Landsat-8 in 2013.

**Table 4.2 Distribution of useable images in March**

| | P28 R31 | P29 R31 | P29 R32 | P30 R31 | P30 R32 | P31 R31 | P31 R32 | P32 R31 | P33 R31 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **1985-1994** | 1 | 4 | 3 | 1 | 1 | 2 | 3 | 3 | 1 | 19 |
| **1995-2004** | 3 | 1 | 3 | 2 | 3 | 2 | 5 | 3 | 2 | 24 |
| **2005-2015** | 4 | 7 | 6 | 7 | 5 | 4 | 5 | 4 | 1 | 43 |
| **March** | 8 | 12 | 12 | 10 | 9 | 8 | 13 | 10 | 4 | 86 |

**Table 4.3 Distribution of useable images in March**

| | P28 R31 | P29 R31 | P29 R32 | P30 R31 | P30 R32 | P31 R31 | P31 R32 | P32 R31 | P33 R31 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **1985-1994** | 5 | 4 | 3 | 6 | 5 | 4 | 4 | 1 | 4 | 36 |
| **1995-2004** | 6 | 3 | 5 | 2 | 3 | 5 | 5 | 3 | 1 | 33 |
| **2005-2015** | 10 | 5 | 4 | 8 | 4 | 7 | 9 | 5 | 4 | 56 |
| **April** | 21 | 12 | 12 | 16 | 12 | 16 | 18 | 9 | 9 | 125 |

The variation trend of inundated wetlands in the combination of March and April data were illustrated in Figure 4.1. The result indicates that inundated areas in playa wetlands decreased over the past 30 years, however, in contrast, the number of inundated wetlands increased from first 10-year period to third 10-year period. This result confirms that wetland variation happened in last 30 years and the wetland conservation efforts had been made in

Nebraska. The degradation of wetlands found in this study further supports the previous research that playa wetlands have been destroyed due to land-use intensification in Nebraska (Jorgensen et al. 2013). And sedimentation, which is caused by intensive agricultural activities, is another main threat to water storage capacity of wetlands (Skagen 2008; LaGrange et al. 2011). The difference between theoretical inundated areas and modified inundated areas discussed in previous section is consistent with previous study that alteration of hydrology at the watershed scale can lead to degradation of wetland inundation areas (LaGrange 2010). On the other side, the increased number of inundated wetlands implies that more functional wetlands have been conserved or restored by successful wetland conservation and restoration programs. A good deal of work for wetland conservation and restoration have been done through federal, state, and local level programs in the past 30 years (LaGrange 2005; Smith et al. 2011; Belden et al. 2012). Thus, more wetland studies are needed to improve the accuracy of wetland mapping for whole state and further detection and monitoring of wetland variations should be applied to assist wetland managers and planners to prioritize conservation and restoration plans.

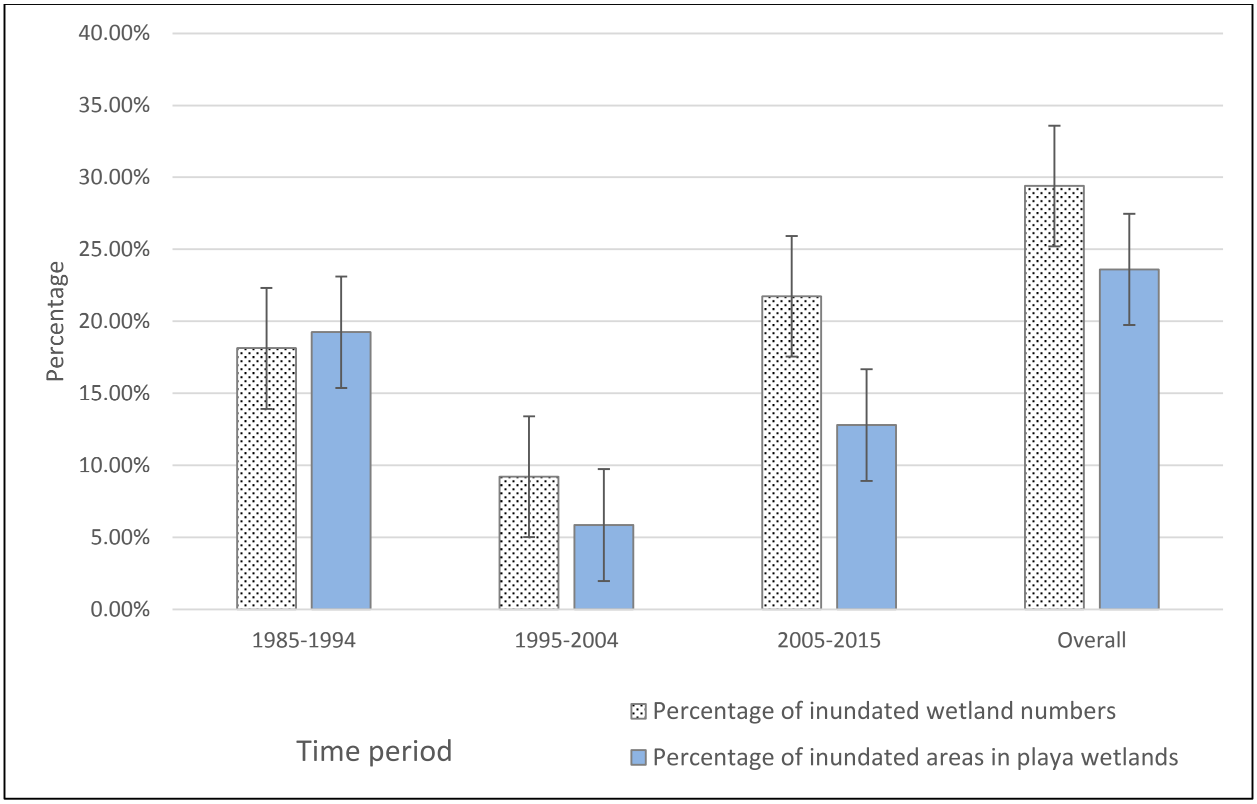


**Figure 4.1 Variation trend of inundated wetlands in the combination of March and April data**

### 4.4 Wetland restoration practices

There has been a variety of wetland restoration projects implemented in playa wetlands over the last decades (LaGrange et al. 1997; LaGrange 2010). But, there is still a lack of enough quantitative methodology and evidence to evaluate and show the effectiveness of practices. Specifically, this study assessed the performance of restoration practices through GIS analysis. And the field survey summarized the existing conditions of wetland programs. This study discussed the frequently used wetland restoration methods and identified the principles to choose the proper restoration methods in playa wetlands, including restoration philosophy, restoration method guidelines, and Wetland Priority Practices. To improve the effectiveness of restoration programs for the variable aspects of wetlands, the study prioritized the variable restoration practices, providing 18 diverse restoration methods based on the previous studies and programs.

Every method focuses on enhancing at least one category of the Wetland Priority Practices. The results identified the most prioritized practices, including the full hydrologic restoration, partial hydrologic restoration, and vegetative restoration; and less prioritized practices, including wetland enhancement and wetland establishment. This sequence illustrates that wetland restoration should focus on historical wetlands rather than creating artificial wetlands. Also, wetland restoration needs a comprehensive package of restoration methods. Any single restoration method or restoration program cannot solve problems that wetlands faced. The long-term restoration strategies with comprehensive methods are needed for the playa wetlands.

# CHAPTER 5 Conclusion

In this study, a cutting-edge platform, Google Earth Engine, was used to process big data. A playa wetland database created from Landsat sensors was completed for all playa wetlands in Nebraska. To identify inundated wetlands, Landsat imagery, ground truth data, and ArcGIS were used. Inundated wetland maps derived from Landsat images were overlaid with playa wetland datasets, which supplements the continuous information of wetlands on long-term and large-area dimension.

The overall inundated area of playa wetlands was 220.63 $km^2$, representing 23.61% of total areas. And the total number of inundated wetlands were 9898, while the total number of wetlands were 33659. Large portion of playa wetlands had never been inundated. Moreover, inundated areas kept decreasing in spring over the past 30 years due to the impacts of climate change, land use change, and alteration of watershed hydrology. However, the increased number of inundated wetlands confirms that wetland conservation and restoration practices have contributed to wetland protection, and are crucial to protect and recover functional playa wetlands in the future. In conclusion, it is not perfect but useful to monitor wetlands with satellite imagery.

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